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What drives the withdrawal of protected areas? Evidence from the Brazilian Amazon

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Abstract

Since the late 1970s protected areas have been one of the most widely used regulatory tools for the conservation of ecosystem services. In this paper, we assess the possible drivers to the choice of withdrawing protected areas in the Brazilian Amazon. Protected areas are subject to inefficiencies because of the existence of conflicts over land between conservation and development activities. Further additionality is an issue, as protected areas tend to be located in areas with low opportunity cost of conservation, where forests are not likely to be cleared. This issue is particularly important in the Brazilian Amazon where growing development must be combined with the need to avoid deforestation. We first present a simple model of degazettement choice which leads us to assess how the presence of two agencies having different development and conservation objectives can lead to implementing this decision. We suggest that the probability to decide the removal of protected areas is larger in places with low and high development pressures. Then, we investigate the empirical determinants of protected area withdrawal by taking advantages of the new PADDDtracker (Protected Area Downgradement, Degazettement and Downsizement) dataset (WWF, 2017b). We confirm that the likelihood of degazettement is strongly influenced by development pressures, through characteristics of the land that enable agricultural development, and by variables related to protected area quality of enforcement and management costs. As protected areas located in highest pressure areas are more likely to be additional, there is a risk that only the most effective protected areas may loose their protection.

Keywords

Conservation policy, PADDD, Land-use change, Brazilian Amazon, Public policy

JEL codes

Q56; Q57; Q58; O13; O21

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1 Introduction

Protected Areas (PAs) are implemented to avoid the degradation of species habitats and biodiversity losses, by regulating resource use and access to land through property rights. Since the beginning of the 1980s, they have been one of the most widely used regulatory tools, firstly for the conservation of biodiversity and then for the conservation of ecosystem services as well as for the maintenance of human well-being (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Following the Aichi Biodiversity Target of the Strategic Plan for Biodiversity 2011-2020 adopted at the 10th meeting of the Conference of the Parties in 2010 in the Convention on Biological Diversity (CBD) (Convention on Biological Diversity, 2011), 14,7% of the worlds ecosystems were classified as PAs in 2016. The most extensive coverage takes place in latin America and Caribbean countries with half of it located in Brazil (UNEP-WCMC and IUCN, 2016). This extension, which is expected to rise until reaching 17% of the earth surface, lead to the emergence of conflicts over land between conservation and development activities (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Indeed, several actors rely on the provision and maintenance of ecosytem services while the establishment of a conservation area may prevent development activities over the territory (Albers, 2010; Nicolle and Leroy, 2017; Naughton-Treves et al., 2005).

The difficulties of managing PAs effectively in the context of the conservation-development trade-off have been widely underlined. First, in order to prevent economic losses due to conflicts over land, PAs are more likely to be established where conservation Opportunity Costs (OCs), i.e. economic pressures, are low (Joppa and Pfaff, 2009; Pfaff et al., 2015a; Pfaff and Robalino, 2012; Baldi et al., 2017). As a result, observing low levels of deforestation where PAs are located does not necessarily mean they have contributed to avoid deforestation (Andam et al., 2008; Pfaff et al., 2009, 2014, 2015a,b, 2016; Joppa and Pfaff, 2011; Ferraro et al., 2013; Nolte et al., 2013; Sims, 2014; Anderson et al., 2016; Kere et al., 2017; Robalino et al., 2017; Jusys, 2018; Abman, 2018). Indeed, what would have occurred without protection is not observable and varies with the amount of pressure occurring in the landscape. Many studies that control for the non-random location of PAs conclude that they are effective in average but not as much as when their non-random location have not been accounted for (Andam et al., 2008; Joppa and Pfaff, 2011; Pfaff et al., 2015b). These results depend on the extent of economic pressures occurring on the landscape as well as on the ability of the PA to be well-enforced in order to prevent development activities (Pfaff et al., 2009, 2014, 2015a,b, 2016; Sims, 2014; Ferraro et al., 2013; Kere et al., 2017; Robalino et al., 2017; Jusys, 2018). The former is linked to the characteristics of the land and to the implementation of political incentives whereas the later is more related to the characteristics of the PA.

The conflicting land uses between PA sitting and development activities may have further influenced their effectiveness as it has triggered Protected Area Downgradement, Degazettement and Downsizement (PADDD) (Watson et al., 2014). These phenomenona, which are in acceleration since the 2000s, are known as legal changes in the status or size of PAs (Mascia and Pailler, 2011). For (Mascia and Pailler, 2011, p. 11), downgradement is "a decrease in legal restrictions on the number, magnitude, or extent of human activities within a PA", downsizement is "a decrease in size of a PA as a result of excision of land or sea area through a legal boundary change" and degazettement is "a loss of legal protection for an entire PA". Their most common proximate causes have been extensively documented in the recent literature and are all related to growing development pressures such as: hydropower development, agricultural extension and rural settlement (Mascia and Pailler, 2011; Mascia et al., 2014; Pack et al., 2016; Bernard et al., 2014; Cook et al., 2017; de Marques and Peres, 2015; Symes et al., 2016). Although PADDD might have impacts on biodiversity and on the attainment of the 2020 Aichi biodiversity targets of the CBD, those impacts in term of conservation outcomes are not well-known and differ according to the inclusion of the past additionality of the PA. When it is taken into account, neither Tesfaw et al. (2018) nor Pack et al. (2016) observe a short-term impact of PADDD on deforestation rates in the state of Rondônia as well as in the Brazilian Amazon between 2000 and 2012. However, Forrest et al. (2015) focus on the large forest carbon emissions that could be caused by PADDD in three tropical countries (Democratic Republic of Congo, Malaysia and Peru) and Golden Kroner et al. (2016) underline the risk of habitat fragmentation in the Yosemite National Park in Australia during its downsizement process.

As PAs tend to be located in low pressure areas and given the fact that PADDD seems to happen where the OC of conservation is high (Symes et al., 2016; Tesfaw et al., 2018), there is a risk that only effective PAs may be downgraded, downsized or degazetted. However, an effective management of PAs could be to make use of PADDD for the least effective one in order to be able to affect resources toward those that are achieving the best (Fuller et al., 2010). As underlined, PADDD decisions are made at the intersection of development and environment objectives. Yet, more research is needed to fully understand how the conflicts between conservation and development activities over land may affect the management and coverage of PAs through PADDD as well as the resulting effectiveness of the PA network. To the best of our knowledge, only Symes et al. (2016) and Tesfaw et al. (2018) empirically study the drivers of PADDD. Symes et al. (2016) find out that the size of the PA influence its probability to be removed while Tesfaw et al. (2018) find out that it is the conservation outcome of the PA that matter the most. Symes et al. (2016) use variables related to the profitability of development activities in 44 countries over 110 years while Tesfaw et al. (2018) propose an analytical framework where conservation and development agencies bargain about PA removal. PADDD is expected when the conservation costs of the decision are low for the environmental agency and when the development benefits that can be generated are high for the development agency. They use a linear probability model on the state of Rondônia, which experienced numerous PADDD events in 2010 and 2014, and suggest that the conservation costs of the decision strongly matter. This conclusion may however vary across governance settings and time periods as it shapes preferences toward development and conservation benefits. Even though Tesfaw et al. (2018) provide a first analytical framework, their analysis remains preliminary and their results are only based on the state of Rondônia for 2010 events regarding PAs that where already ineffective in blocking deforestation pressures.

The objective of this paper is to provide an assessment on how the conservation-development trade-off may trigger losses of protection in the Brazilian Amazon. Our contribution is twofold: first theoretical, then empirical. Following the analytical framework of Tesfaw et al. (2018), we go further into detail on each agency decision rule and we make them interacting with the conservation OCs varying over the territory. We argue that the concept of OC is a complex one, that encompasses several transmission channels that determines the effectiveness of PAs, their management costs and the pressures they face. Some channels concern essentially the environment objectives of the policy maker, while others focus more on the development objectives. Therefore, our first contribution is to theoretically disentangle the various channels that defines the OCs of maintaining PAs. Our simple model of degazettement choices assesses how the interaction between the environment and development agencies with different development and conservation objectives can lead to the implementation of this decision. Our approach distinguishes itself from previous research: after describing the objectives of the two players and the various components of conservation OCs, we consider several cases of interactions between them to analyse how degazettement decisions are undertaken when the conservation OCs varies over the territory. We propose distinguishing two main channels to describe how these variations can bring about PADDD: i) A Low Benefit (LB) channel for PAs that are greatly biased in location (i.e. situated over lower OCs area). They are difficult to maintain, even though they are less subject to conflicts over land and better enforced, since their additionality is likely to be very low. ii) A High Cost (HC) channel for PAs that are not biased in location (i.e. situated over higher OCs area). They are difficult to maintain, even though they are highly additional, since they are more subjects to conflicts over land and less likely to be well-enforced.

This issue is particularly important in Brazil, which is likely to face political and economic pressures that facilitate the significant rise of PADDD (Bernard et al., 2014; de Marques and Peres, 2015; Symes et al., 2016). Despite the considerable efforts of the Brazilian government to extend and to harmonize its PA network since 1980, nearly 20% of the total area covered by the Brazilian system of PAs (SNUC - Sistema Nacional de Unidaded de Conservação) has been lost. Since 2000, as a result of economic development pressures, proposed PADDD has increased in the Brazilian Amazon (Veríssimo et al., 2011) and 13,000 km^2 of deforestation has been observed inside conserved areas in 2009 (Veríssimo et al., 2011), which is 3.5% of the total deforestation observed from 1998. This has been helped by the shifting attitude of the Brazilian government toward agricultural and economic pressures, which has become more sensible to increasing political lobbying (Soares-Filho et al., 2014; Bernard et al., 2014). In 2012, this resulted in the implementation of a new forest code which might make development project easier to realize (Soares-Filho et al., 2014). Therefore, our empirical contribution relies on testing the model, using the PADDDtracker dataset (WWF, 2017b). First, we empirically assess conservation OCs through characteristics of the land and of PAs which enter in each agency decision rule. Second, as the decision of degazettement is a latent binary variable, we use a logistic probability model estimated by the maximum likelihood method to investigate on the empirical determinants of PA degazettement. Since we believe that the weight attributed to conservation and development objectives is influenced by the fixed characteristics of each state (Pfaff et al., 2015a,b; Abman, 2018; Ferraro et al., 2013), we use state dummies to catch unobserved heterogeneity that may influence PADDD decisions. We confirm that the likelihood of degazettement is higher in areas with high OCs of conservation. We emphasize the positive role of the proximity to roads and low external population density on the likelihood of PADDD since it increases the expected benefits of agricultural extension. Environmental objectives seem to matter as well when pressure are high since PAs that are badly enforced and costly to manage because of their fragmentation are more likely to lose their protection status. When pressures are low, PAs may still be degazetted because of their lack of potential additionality. We suggest that the characteristics of the land entering in the OCs of conservation as well as the bargaining power of each agency are likely to differ according to PA location, type and level of governance.

This article is organized as follows: Section 1 present the objectives of the two agencies in the economic model of degazettement choices. In section 2, we analyse various types of interactions between the environmental and the development agencies to explain how the combination of their objectives may lead to PA degazettement. In section 4, we present our empirical strategy, the construction of our database and the results of the estimations. Section 5 discusses and concludes.

2 A simple economic model of degazettement choice

We consider a set of PAs that have been implemented in the past. For various reasons (institutional or political change, impact evaluation), those PAs have to be evaluated; the choice has to be made of which PAs will remain implemented, and which will be degazetted.

We consider two institutional players: an environmental agency (EA) and a development agency (DA). For every PA i, the choice to degazette the PA ($D_i = 1$) or not ($D_i = 0$) has to be made. The main variable that will influence the choice to degazette is the OC of conservation in the area o_i. Further, we consider that the OC is a composite variable, that encompasses a set of transmission channels affecting either the EA or the DA, and leading to the political decision of PA withdrawal. More precisely the characteristics of the land and of PAs that have an influence on (i) development pressures in the area and (ii) the additionality potential of the PA. Development pressures tend to increase the economic gain of withdrawing the PA (which is the restrictive definition of opportunity costs), but also to increase the likelihood that the PA is not well enforced (due to poaching, illegal logging or land conversion). Related to that, the OCs also increase the additionality potential of the PA: low OCs areas are likely to be unthreatened, and PAs implemented in those areas are then likely to have low additionality.

2.1 Development agency

The DA entirely focuses on development objectives, which means that PAs necessarily represents a constraint to those objectives. This constraint is increasing in the OC o_i. wo_i represent the DA's potential expected economic gains if the PA is degazetted.

The DA's utility from degazettement and his degazettement decision rule are thus:

$$\begin{aligned} U_{DA}(D_i) &= wo_i D_i \qquad (1)\\ D_i &= 1 \; \forall \, o_i > 0 \\ D_i &= 0 \; \forall \, o_i = 0 \end{aligned}$$

Thus, the DA would prefer that all PAs with positive OCs be degazetted, but his preference is stronger for PAs where OCs are larger.

2.2 Environmental agency

The environmental agency evaluates the PA effectiveness when deciding to degazette or not. The cost of PA i implementation is $C_i(o_i)$, while its environmental benefit is $b_i(o_i)$. Thus the EA utility, her net benefit from degazettement ($B_i(o_i)$) and the decision rule of the AE are:

$$\begin{aligned} B_i &= C_i(o_i) - b_i(o_i) \\ U_{EA}(D_i) &= B_i D_i \\ D_i &= 1 \ \forall \, C_i(o_i) > b_i(o_i) \\ D_i &= 0 \ \forall \, C_i(o_i) \leq b_i(o_i) \end{aligned} \tag{2}$$

The management cost $C_i(o_i)$ in (3) is composed of two elements: a fixed cost h_i and a variable cost $c_i(o_i)$: enforcement is more costly in areas where economic pressure is higher. Variable costs are increasing and convex in OCs.

$$C(o_i) = h_i + c(o_i) \tag{3}$$

The environmental benefits $b_i(o_i)$ in equation (4) depends on (i) the PA potential additionality in terms of avoided deforestation $e_i(o_i)$ and (ii) the probability of the park unit to be well-enforced $p_i(o_i)$. Potential additionality is increasing and concave in OCs o_i and the enforcement probability is decreasing and convex. PAs are expected to be more additional in terms of avoided deforestation on areas where development pressures are high[1] but are more likely to be ineffective due to lack of enforcement.

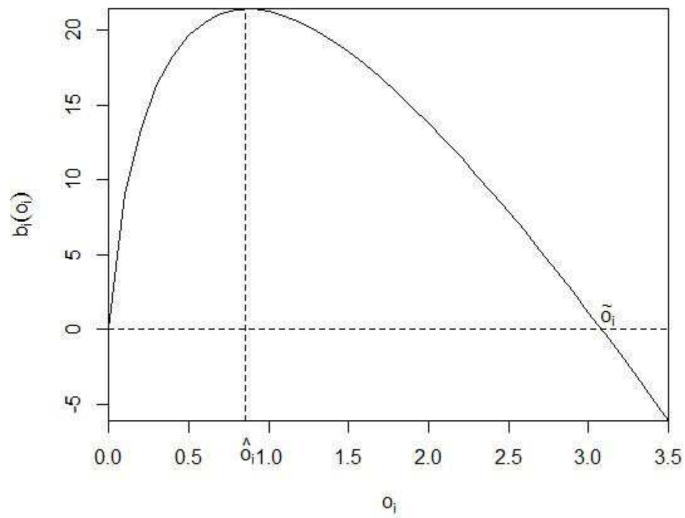
$$b_i(o_i) = p_i(o_i) e_i(o_i) \tag{4}$$

Thus, one can expect a inverted-U shaped form of environmental benefits from the PA (figure 1)[2]. When OCs are low, the probability of enforcement is high, but the potential additionality is low. When o_i increases, enforcement probability first decreases slowly while potential additionality rapidly increases. Thus, environmental benefits increases. When OCs reach a certain point $\hat{o}_i$, the negative effect on enforcement probability becomes larger than the positive effect on potential additionality, and environmental benefits start decreasing, until they reach 0 again for a certain level $\tilde{o}_i$ of OCs.

[1] If we consider a biodiversity conservation objective, additionality is also higher in areas where biodiversity is richer. This will be considered in the empirical section.

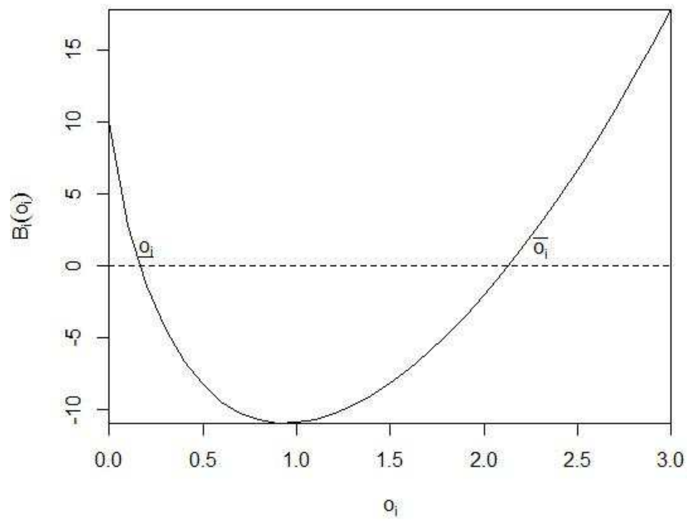
[2] Calibration for our illustrative simulations is provided in appendix.

Figure 1: Expected environmental benefits



When combining the management cost and the environmental benefit, the net benefit from degazettement ($B_i(o_i)$) takes the form of a U-shaped function (figure 2). When OCs are null, the net benefit from degazettement equals fixed costs from PA maintenance. As o_i increases, the net benefit from degazettement are first decreasing: the increase in management costs is lower than the increase in environmental benefit. It will decrease until the point where its marginal cost from PA management equal her marginal expected benefits from it : $\frac{\partial c_i(\tilde{o}_i)}{\partial \tilde{o}_i} = \frac{\partial e_i(\tilde{o}_i)}{\partial \tilde{o}_i} p_i(\tilde{o}_i) + \frac{\partial p_i(\tilde{o}_i)}{\partial \tilde{o}_i} e_i(\tilde{o}_i)$. After that point, for higher level of OC, her net losses increase again because she is still facing increasing management cost minus diminishing expected environmental benefits.

Figure 2: Net benefits from degazettement



3 Degazettement choice

First, we focus on the simple case where the EA is the only decision maker. Second, the case of joint-maximization is considered.

3.1 Environmental agency as the only decision maker

In this case, we consider that the degazettement choice is made only considering the EA's payoff. In order to determine when the environmental agency decides to degazette or not the area to maximize her utility $U_{EA}(D_i)$, we have to find the level of OCs for which the net benefit from PA degazettement are positive or negative, and the variable influencing this result. As mentioned before, the payoff from degazettement has a U-shaped form. Thus, an interval $[\underline{o}_i, \bar{o}_i]$ inside (outside) which the payoff from degazettement is negative (positive) is likely.[3]

When the EA has a net benefit from PA degazettement ($o_i < \underline{o}_i$ and $o_i > \bar{o}_i$), she decides to degazette the area ($D = 1$). For low OCs, she prefers to degazette the area because her fixed cost h_i are too high compared to her expected benefits given the low additionality of the parc: we call that the low benefit (LB) channel. For high value of OCs, her overall management costs $C_i(o_i)$ are too high compared to her expected environmental benefits $B_i(o_i)$ due to high economic pressures: the High Cost (HC) channel. For intermediate value of development pressure, expected benefits from degazettement are negative as her costs from PA maintenance are smaller than expected environmental benefits. She thus chooses to maintain the area ($D = 0$) to maximize her utility.

What drives the decision rule for the environmental agency?

Values of OCs of conservation for which the EA decides to shift her decision of degazettement, either due to high pressure in the HC channel or due to low additionality in the LB channel, can vary depending on her overall management costs, on the enforcement probability and on the PA expected additionality.

We can obtain situations were the EA decides to take more (less) degazettement decisions in both channels (higher -lower- $\underline{o}_i$ and lower -higher- $\bar{o}_i$) if higher (smaller) fixed costs make the net benefits from PA degazettement displacing upward (downward) (figure 3). If the PA expected additionality is increasing faster (slower) with OCs, the EA will take more (less) degazettement

[3]There can also be extreme cases where the payoff is always positive (in this case, degazettement always takes place) or partially negative (degazettement is implemented only for highest values of development pressures).

decisions in the LB channel and less (more) degazettement decisions in the HC chanel ($\underline{o}_i$ and $\bar{o}_i$ are both higher -lower-) (figure 6). Indeed, the EA's payoff decrease slower (faster) with OCs when development pressures are low and increase slower (faster) when they are high. If the EA's variables costs are increasing faster (slower) with OCs, the EA will take more degazettement decision in the HC chanel (lower -higher- $\bar{o}_i$). Indeed, the EA's payoff from PA degazettement is increasing faster (slower) with OCs in the HC channel (figure 4) while it has a weak effect and stay the same in the LB channel. The same phenomenon is happening when the PA enforcement probability is decreasing faster (slower) with OCs (figure 5).

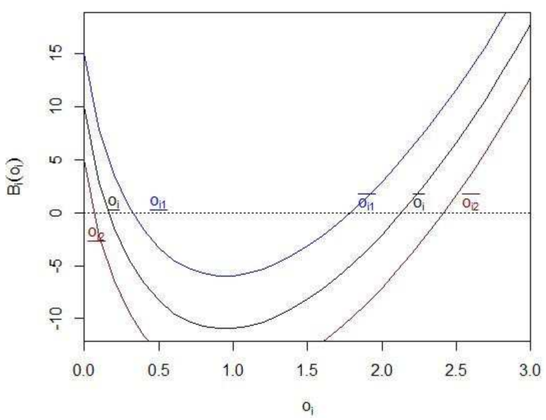


Figure 3: Impact of fixed costs on PA degazettement

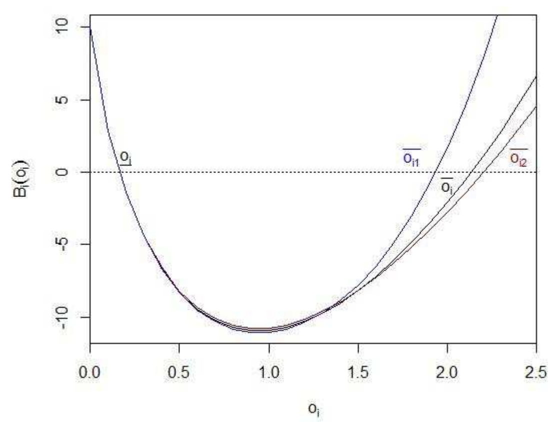


Figure 4: Impact of cost convexity on PA degazettement

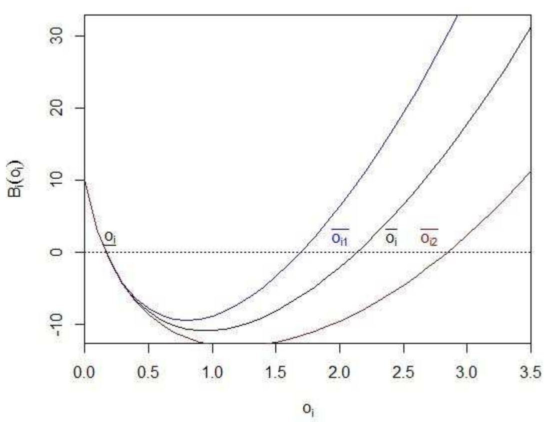


Figure 5: Impact of enforcement probability on PA degazettement

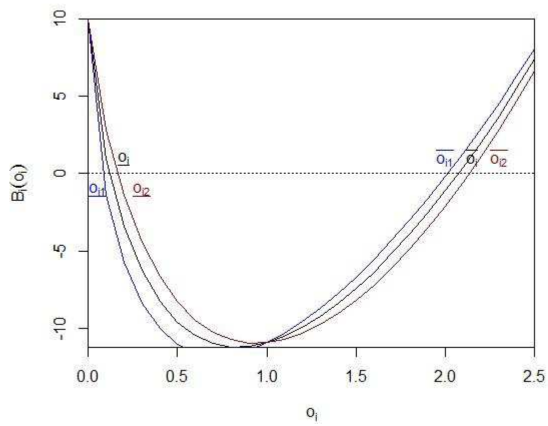


Figure 6: Impact of expected additionality on PA degazettement

The empirical analysis will allow us to verify whether the EA behaves as in our economic model. If a lot of (few) degazettement are observed in the HC channel, it may be the effect of high (low) fixed costs, fastly (slowly) increasing variable costs with OCs, fastly (slowly) diminishing PA enforcement probability or slowly (fastly) increasing PA expected additionality. If a lot of (few) degazettement are observed in the LB channel, it may be driven by high (low) fixed costs or fastly (slowly) increasing PA expected additionality with OCs. When taken together, the effet of these variables are likely to reinforce or mitigate each other effect.

3.2 Joint maximization with asymmetric weights

We assume that the degazettement choice is made balancing the EA and DA's payoffs. It may be the case if a government aims to balance the environmental and development interests. In order to investigate the behavior of a central decision maker, both environmental and development agency utility functions are taken into account in a social benefits function from PA degazettement Ω_i (equation 5). The decision maker can assign different weightings z to environmental and development objectives according to social preferences:

$$\Omega_i = zB_i + (1-z)\,wo_i \quad \text{with} \quad z \in [0;1] \tag{5}$$

The central regulator follows a decision rule JM with the objective of maximizing social benefits from PA degazettement:

$$\begin{aligned} JM(D_i) &= \Omega_i D_i \\ D_i &= 1 \;\forall\; (1-z)\,wo_i > zb_i(o_i) - zC_i(o_i) \\ D_i &= 0 \;\forall\; (1-z)\,wo_i \leq zb_i(o_i) - zC_i(o_i) \end{aligned} \tag{6}$$

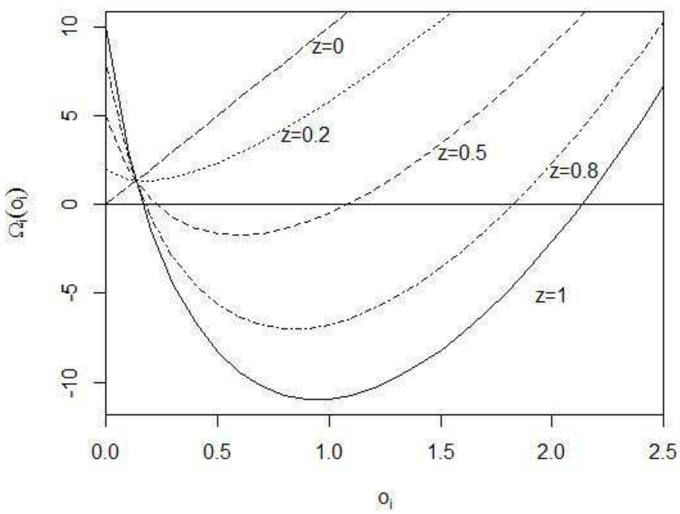
When $z = 0$, the regulator behaves as if the DA were the only decision maker and social benefits from PA degazettement are equivalent to DA's expected development profits from PA degazettement wo_i. When $z = 1$, only environmental goals matter and the regulator behaves as if the EA were the only decision maker. Social benefits from PA degazettement are equivalent to EA's net benefit from PA degazettement $B_i(o_i)$.

When $z \in]0,1[$, both environmental and development goals matter though their weight are not the same. Therefore, PAs are degazetted if their potential expected development profits wo_i from being degazetted are higher than the net environmental benefits from being maintained. In other words, to maintain a PA, the overall management costs have to be lower than the difference between its environmental benefits and the expected profits that could be done if the area were degazetted (equation 7). Results in terms of PA degazettement will depend on particular weights

z given to environmental and development objectives in the society (Examples with diverse weight are provided in figure 7).

As economic development starts to matter in social preferences ($z < 1$), social benefits from PA degazettement will change compared to the case where only the EA's payoff were considered $B_i(o_i)$. First, the smaller weight given to the EA's payoff makes $\Omega(o_i)$ less convexe with a lower intercept. Then, the inclusion of the DA's payoff makes $\Omega(o_i)$ rotating upward compared to $B_i(o_i)$, which have an impact on the values of OCs for which degazettement is implemented. If $z > 0.5$, nothing changes in the LB channel as the effect of the EA decision rule is strong enough in social benefits from PA degazettement. If $z < 0.5$, the effect of the EA decision rules is no longer sufficiently strong: more degazettement is expected in both LB and HC channels. Therefore, when development preferences are strong enough, all PAs are degazetted[4].

Figure 7: Social benefits from PA degazettement with diverse weight



4 What are the determinants of PADD in the Brazilian Amazon?

4.1 Theoretical predictions to be empirically tested

Our theoretical model suggests that the probability to decide the degazettement of PAs is larger in places with low OCs, or high OCs, because of the various transmission channels that we have

[4]The case where both the EA and the DA are cooperating in order to know the value for which one area will be degazetted has also been developed and is available in the appendix. Results are equivalent to those of a joint maximisation with equal weights.

identified. This probability is lower when OCs are intermediate. When OCs are low, expected development benefits are positive and there is low additionality of the PA, meaning it can be degazetted at low environmental costs. When OCs are high, expected development benefits are much higher and the PA may be ineffective because high development pressures make enforcement too costly. For the EA, degazettement decisions should depend on: i) the cost of maintaining the PA unit protected which is composed of a fixed part and a variable part; ii) the expected environmental benefits of maintaining it. For the DA, degazettement decisions are made as soon as the expected development profits that can be made in the area are positive. All these elements of decision depend on the OC of conservation that vary over the landscape.

In this section, the determinants of a strict loss of protection of PAs in the Brazilian Amazon are empirically investigated. The OC of conservation is assessed through a composite measure of characteristics of the land and of PAs which are expected to enter in the expected development profits, expected additionality and enforcement probability of each still protected and degazetted PA units. We use standard characteristics known to be good predictors of PA location toward area of low profitability. This allows us to investigate on whether PAs lose protection due to high pressure or due to low benefits. Furthermore, the kind of conservation-development interactions at stakes in the management of PAs can be assessed.

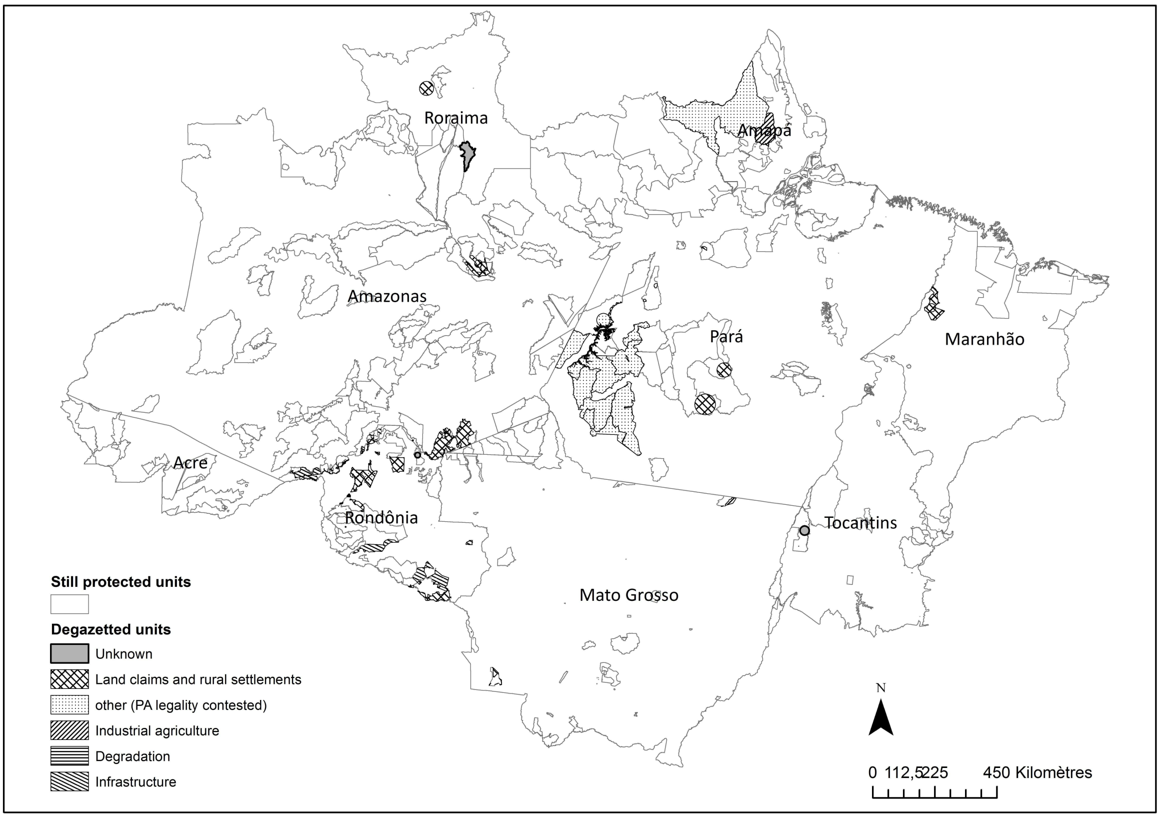
The evolution of the conservation-development trade-off toward more protection in the Brazilian Amazon during the two last decades makes the assumption of the DA being the only decision maker very unlikely. Moreover, since the causes of degazettement appear essentially linked to development processes, the EA being the only decision maker appears also to be very unlikely. Thereby, the possible results from the empirical model should either indicate the existence of a decision process that is made balancing environmental and development objectives with asymmetric weights or a cooperation between the two agencies in order to maximize a joint payoff.

4.2 Data and empirical strategy

4.2.1 Observation Unit

We use PADDDtracker and the World Database on Protected Areas (WDPA), which are spatially explicit databases of PADDD and PAs from the World Wildlife Fund (WWF, 2017b) and from the IUCN (IUCN and UNEP-WCMC, 2017). These two databases allow us to have the precise identification, location and description of each PADDD and still existing PAs with comprehensive information on their characteristics from 1970 to 2015. PADDD events are classified according to their type (degazettement, downsizement or downgradement), status (enacted or proposed) and according to the cause of the decision. Other available and valuable information include the year of the decision as well as its description before and after the PADDD decision has been made.

Figure 8: Causes of PA degazettement and downsizement



The Brazilian Amazon is composed of nine states (Roraima, Amazonas, Acre, Rondônia, Amapá, Pará, Mato Grosso, Tocantins and the western part of Maranhão) covering a territory of more than 5 millions squared kilometers. In 2010, 43.9% of the territory was under PAs as defined by the SNUC, namely Conservation Units (CUs), covering 23.5% of the land, and territories of traditional occupation (Indigeneous Land and Quilombola Territories) (Veríssimo et al., 2011). CUs are managed by the federal, municipal or by the state governments and can be classified according to their degree of permitted intervention (strict conservation or sustainable use).

Until 2014, 77 PAs have experienced PADDD in the Brazilian Amazon (Pack et al., 2016), mostly downsizement (44 events) and degazettement (30 events), resulting in the loss of more than 20% of the PA estate (Veríssimo et al., 2011). Among them, 48 are enacted (i.e. passed into law) and 29 have a more ambiguous status and remain proposed (i.e. not yet passed into law)

(Pack et al., 2016). Even though the creation of PAs follows a strict process of civil discussions and technical studies, PADDD decisions are proposed and then enacted by federal or national authorities without any consultation (Bernard et al., 2014; Pack et al., 2016; Veríssimo et al., 2011; Bernard et al., 2014; WWF, 2017b).

Our observation unit is the intersection between PADDDtracker and the WDPA. We use both proposed and enacted events as we are interested in explaining the intention to remove protection. Besides having no access to the time required for a proposed degazettement to be enacted, those that have passed into law have not necessarily been implemented. The only available information is the final cause of the decision, which is expected to result from various structures of preferences toward development and environmental objectives. Territories of traditional occupation have been excluded from the intersection to avoid misleading overlaps as they are not involved in PADDD decisions (Veríssimo et al., 2011). In addition to degazettements (30 events), the analysis has been extended to downsizements (44 events) because these decisions also represent a complete loss of protection for a unit of CU. However, downgradements have been excluded from the sample as they are not considered as strict losses of protection and because many of them come from reclassifications due to the establishment of the new SNUC (Bernard et al., 2014).

Data for our explanative variables have been found within a 2000-2005 period of time, as a result, we explain the probability of PA degazettement and downsizement from 2006 to 2015. This choice allows us to avoid endogeneity issues by using variables describing the history of the landscape before any decision has been made. This range of years is considered to be enough as degazettements and downsizements have mostly been taken from 2006 onwards (51 events with 30 degazettements and 21 downsizements). We thus obtain 332 observation units that are either intact (281 observations) or that have been degazetted during the period (51 observations). A dummy variable taking the value of one (and zero otherwise) has been attributed to each unit if a decision of degazettement or downsizement has been observed.

4.2.2 Empirical strategy

Our objective is to estimate the probability for a unit of PA to loose its protection status. This decision is based on the net utility the decision maker expect to get when he decides to remove a PA unit $U(D_i)$.[5]

[5] $U(D_i)$ representing $U_{EA}(D_i)$, $U_{DA}(D_i)$ or $JM(D_i)$, depending on the hypothesis on who is the decision maker. As discussed above, we consider the joint-maximisation option as the most likely and most general case.

We thus want to estimate the following model:

$$U^*(D_i) = \beta_i X_i + \epsilon_i \tag{7}$$

With $U^*(D_i)$ being the non-observed utility that is expected from degazetting one unit of CU i, X_i the vector of covariates entering in the utility of the decision maker, β their associated parameters and ϵ the error term. As our dependent variable $U^*(D_i)$ is latent, we consider a dummy variable d_i which takes the value of one when a decision of degazettement or downsizement is taken and 0 otherwise:

$$\begin{cases} d_i = 0 \ \ if \ \ U(D_i) \leqslant 0 \\ d_i = 1 \ \ if \ \ U(D_i) > 0 \end{cases} \tag{8}$$

As a result, the probability for a unit of CU i to be degazetted is estimated by a binary variable model which takes the form of equation 9. The vector of covariates X_i represents the linear combination of the characteristics of the land and CUs entering in the DA's expected development profits $w(o_i)$ and in the EA's net benefits $B_i(o_i)$ from the degazettement of each unit i of CUs (equation 10).

$$Pr(d_i = 1) = F(\beta_i X_i) \tag{9}$$

We assume the cumulative distributive function of our residuals to be logistic, hence, we use a logistic probability model estimated by the maximum likelihood method. The reduced form of the model is as follows:

$$\begin{aligned} Pr(d_i = 1) &= w_i(\alpha o_i) + p_i(-\sigma_1 o_i + \sigma_1^2 o_i) - e_i(\sigma_2 o_i) + c_i(\sigma_3 o_i) + C_i + \delta_i + \epsilon_i \\ &= w_i(\alpha_1 o_i + \alpha_2 o_i) + p_i(-\sigma_1 o_i + \sigma_1^2 o_i) - e_i(\sigma_2 o_i) + c_i(\sigma_3 o_i) + C_i + \delta_i + \epsilon_i \end{aligned} \tag{10}$$

The DA's expected development profits w_i are first approached by the level of development of the area where the CU is located (equation 10). Afterwards, the OC of conservation entering in the DA's expected development profits are broken down in two parts: $\alpha_1 o_i$ and $\alpha_2 o_i$, which respectively stands for the characteristics of the land that directly affect the return from infrastructure implementation and land claims, two main proximate causes of degazettement and downsizement decisions (figure 8 below) (Mascia et al., 2014; Pack et al., 2016; de Marques and Peres, 2015; Tesfaw et al., 2018; WWF, 2017a). The OC of conservation entering in the EA's expected benefits from degazettement is composed of characteristics of the land and of CUs $\sigma_1 o_i$ $\sigma_2 o_i$ $\sigma_3 o_i$ that respectively enter in the probability of the unit of CU to be well-enforced p_i, the expected environmental benefits e_i and the fixed and variables management costs (c_i and C_i). We believe that the bargaining power of each agency is influenced by the fixed characteristics of each state (Joppa and Pfaff, 2011; Nolte et al., 2013; Abman, 2018) and by their different behavior toward environmental and development objectives (Pfaff et al., 2015a,b; Ferraro et al., 2013; Tesfaw et al., 2018). For example, the numerous degazettement of the state of Rôndonia compared to those of Amazonas make us think that there could be spatial patterns across the decision processes through the local benefits and costs associated with PA management (Sauquet et al., 2014). We account for this unobserved heterogeneity by including state dummies δ_i in the estimation.

4.2.3 Description and treatment of covariates

Development Agency covariates

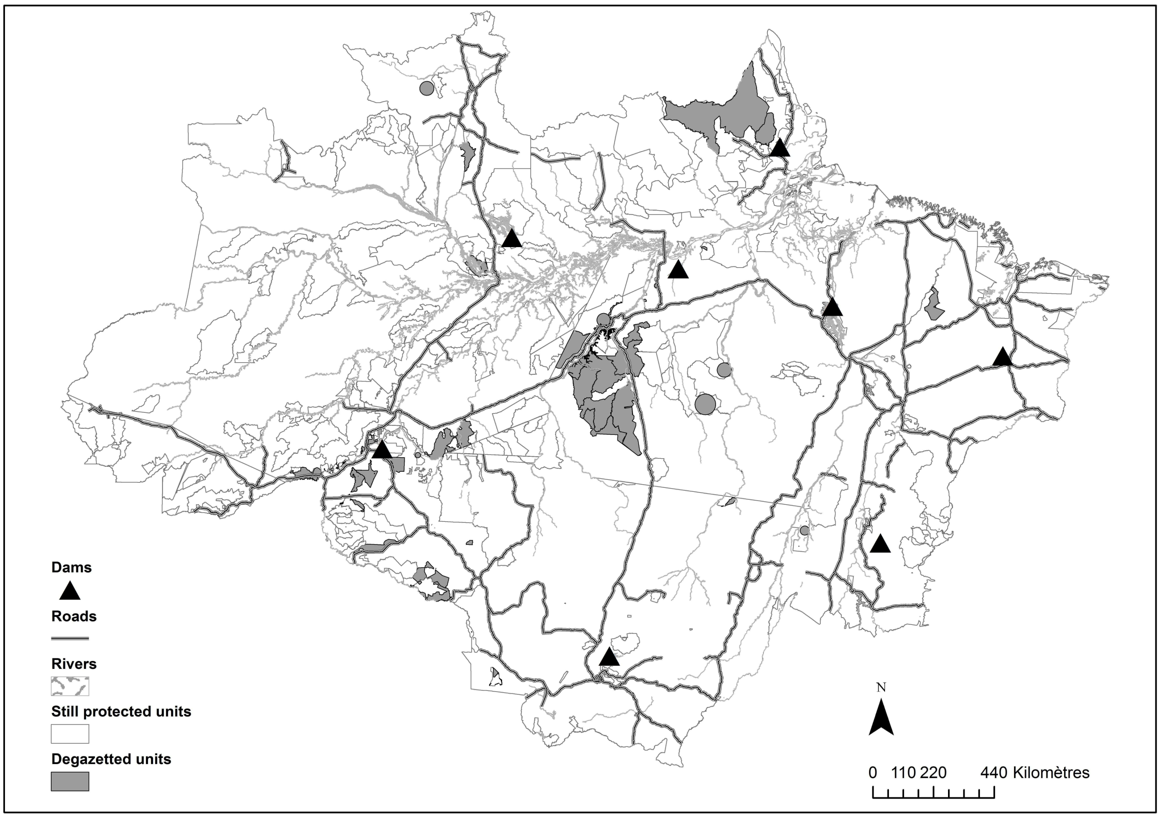
First, we use the average and the growth rate of the Growth Domestic Product (GDP) from 2000 to 2005 (IBGE, 2017) as a proxy for the economic development through the industrialization process of the municipalities that overlap with CUs. We believe it to be a strong predictor of pressures coming from the agribusiness sector and thus to rise the OC of conservation (Bernard et al., 2014; Kere et al., 2017; Joppa and Pfaff, 2009; Ferraro et al., 2013; Sims, 2014; Pfaff et al., 2015a; Mascia et al., 2014; Symes et al., 2016).

Afterwards, we assess the land characteristics that affect the benefits from economic development from land claims and infrastructure implementation (Tesfaw et al., 2018).

Those rising the returns from land claims, either for rural settlement or for the extension of agricultural activities are approximated by the accessibility of the CU to markets, the profitability of agricultural activities and the population pressures in the CU. We use the distance to the nearest road in 2006 (DNIT, 2017) because it is expected to positively influence the accessibility of the CU to markets (Laurance et al., 2014, 2009; Bax and Francesconi, 2018; Bax et al., 2016; Jusys, 2018; Barber et al., 2014) (figure 9). The average rainfalls from 2000 to 2005 (Funk et al., 2015) are included to proxy the suitability of lands for the extension of agricultural activities (Sombroek, 2001; Kirby et al., 2006; Kere et al., 2017; Tesfaw et al., 2018; Bax and Francesconi, 2018; Bax et al., 2016). The population pressures are approximated by the average population density occurring in the area between 2000 and 2005 (CIESIN, 2015).

The characteristics of the land rising the returns from infrastructure implementation are approximated by the average slopes (Jarvis et al., 2008) and by the proximity of the PA to rivers (IBGE, 2017). Indeed, being located nearest to rivers and on higher slopes (figure 9) may make the lands more suitable for the implementation of hydroelectric dams (Finer and Jenkins, 2012; McClain and Naiman, 2008). We focus on this type of infrastructure because hydropower development is the first objective of infrastructure implementation in the Brazilian Amazon (Fearnside, 2014; WWF, 2017a; Araújo et al., 2012).

Figure 9: Roads, rivers and dams



Environmental Agency covariates

Total forest losses from 2001 to 2005 (INPE, 2017) is used as the characteristic of the land entering in the probability of the CU to be well-enforced. CUs which have experienced higher total deforestation during the period are considered to be badly enforced compared to those who have not. The probability of being well enforced is assumed to be low if deforestation occurs within the CU. We make the non-linear effect of enforcement lying on the strength of forest clearings which indicate differences in the level of pressure. Therefore, this variable has been included in its square shape to distinguish between areas of high pressure, which have a low probability of being correctly enforced and areas of low pressure which have a higher probability. We use a factor variable standing for the number of terrestrial endemic species (WWF, 2006) and the proximity to existing dams as characteristics of the land entering in the expected environmental benefits of maintaining PAs. Indeed, the number of endemic species represent a motivation to attain the target of the

CBD and has been used as a planning tool to assess biodiversity priorities in areas which deserve greater attention due to environmental threats (Olson et al., 2001). This variable is expected to have a negative influence on the likelihood of degazettement if environmental priorities matter (Tesfaw et al., 2018). Being close to existing dams may have a negative influence on the expected environmental benefits of PA maintenance due to the impacts it may have on the fragmentation of habitats and the emissions of greenhouse gas (Fearnside, 2014; Finer and Jenkins, 2012; McClain and Naiman, 2008).

The management costs of the CU can decrease or increase with the size of the CU depending on the existence of economies of scale (Bruner et al., 2004). As a result, we first use the ratio of their perimeter to their area (WWF, 2017b) as a proxy for the CUs' variable management costs. The area-to-perimeter ratio is frequently used to measure habitat or PA fragmentation (Sims, 2014; Albers, 2010). Indeed, CUs that have a low perimeter to area ratio are expected to face more human pressure (e.g. poaching, illegal logging) due to the length of their edge compared to the size of their core area (Albers, 2010). High variable costs compared to fixed one make the existence of economies of scale unlikely. We use the size of the CU to further control for fixed costs of management due the impacts it has on the human and technical resources needed for enforcement (Robinson et al., 2011; Albers, 2010). It has also been found to have an effect on the likelihood of PADDD (Symes et al., 2016) since it is directly related to the OC of its existence compared to other type of land uses (Veríssimo et al., 2011; IUCN and UNEP-WCMC, 2017; Symes et al., 2016). Lastly, the International Union for Conservation of Nature (IUCN) category (WWF, 2017b) of the CU is used to obtain supplementary information on the management objectives of each one of them. This can inform us on the type of issues and thus fixed costs faced by the EA (Bruner et al., 2004; IUCN and UNEP-WCMC, 2017; Symes et al., 2016).

All the covariates were transformed in Geographic Coordinate System "South American Datum 1969" and projected into "UTM Zone 18S (meters)" using ArcGIS 10.4.1. The raster and vector covariates have not been treated similarly. A precise grid of 1,8km by 1,8km have been drawn to sample the raster dataset (slopes, population density and rainfalls) at the same scale. Then, we have extracted their mean over each square using zonal statistics, which allows us to obtain their complete distribution over each observation unit. This choice has been made because it makes us able to describe our smallest degazetted or downsized CU. Only the average of their distribution and the weighted average of their proportion over the CU have been included in the final estimations. The vector covariates (GDP, number of endemic species and deforestation) have directly been intersected with CUs to obtain the exact proportion of their values over each one of them. Geodesic distances to the nearest road, dam and river have been computed in kilometers from the centroid of each CU. A complete description of the source and statistical treatment of the covariates is available in table 6 in the appendix.

4.3 Results

A description of the main summary statistics of our covariates, broken down by still protected (1) and degazetted CUs (2), is available in the appendix (tables 5, 6 and 7). We observe some differences between land characteristics on still protected and degazetted CUs that are confirmed by significant Student's t-statistic on the equality of mean and Pearson's pairwise correlations (table 8). On average, degazetted CUs seem to be located on areas with higher GDP from 2000 to 2005, with their centroid being closer to roads in 2006. However, we observe a negative correlation between the average population density and the decision of degazetting a CU. In addition, degazetted CUs were located on areas that were larger, more deforested from 2001 to 2005 and that were endowed with a lower number of terrestrial endemic species.

4.3.1 Basic specification

Our basic specification is presented in table 1 below. As mentioned, we first estimate the probability of CU degazettement and downsizement with a simple logit model (1) in which the conservation OCs entering in the DA's preferences are represented via the average GDP at the municipal level. In the second model (2), they are broken down to integrate the characteristics of the land rising the expected profits from development activities at the level of the CU. In the third model (3), we go further to look at the characteristics of the land (forest cover losses, average population density and average rainfalls) in the 10km buffer zone of the CU. These external pressures might enter in the quality of enforcement of the CU and on the profitability of development activities. The average GDP at the municipal level is not included in these two last estimations to avoid colinearity between the explanatory variables. Finally, in model (4), we assess the impact of the location of the CU toward pressures with the distance to the forest edge. In each model, the conservation OCs entering in the preferences of the EA are entirely assessed.

Our results in model (1) indicates a positive but weak effect of the average GDP at the level of the municipality on the likelihood of degazettement. The economic development of the municipalities overlapping with CUs does not seem to matter much in enabling pressures coming from the agribusiness and infrastructure sectors. This is not consistent with the development objectives having some weight in the decision process of degazettement (Bernard et al., 2014; Mascia and

Table 1: Basic specification

Logit	(1)	(2)	(3)	(4)
The Development Agency				
Average GDP	1.410			
	(1.92)*			
Average slopes		4.848	4.143	4.093
		(2.09)**	(1.67)*	(1.68)*
Distance to the nearest river		0.645	0.696	0.741
		(-1.37)	(-1.18)	(-0.91)
Average rainfall		1.000	1.000	0.999
		(0.51)	(-0.12)	(-0.57)
Average rainfall in the buffer zone			1.001	
			(0.32)	
Average population density		0.923	2.043	2.669
		(-0.21)	(1.64)	(2.22)**
Average population density in the buffer zone			0.487	0.454
			(-2.22)**	(-2.37)**
Distance to the nearest road		0.456	0.436	0.450
		(-3.42)***	(-3.10)***	(-2.85)***
The Environmental Agency				
Total deforestation	0.679	0.662	0.669	0.610
	(-2.88)***	(-2.62)***	(-2.79)***	(-3.33)***
Squared total deforestation	1.020	1.025	1.025	1.030
	(2.83)***	(3.10)***	(3.42)***	(3.80)***
Total deforestation in the buffer zone			0.988	
			(-0.37)	
Distance to the forest edge				0.490
				(-2.24)**
High endemism (>21)	0.649	1.012	0.876	1.661
	(-0.26)	(0.01)	(-0.09)	(0.35)
Low endemism (1-5)	0.400	0.343	0.264	0.592
	(-1.16)	(-1.29)	(-1.47)	(-0.53)
Medium endemism (6-20)	0.598	0.483	0.478	0.806
	(-0.79)	(-1.08)	(-1.04)	(-0.27)
Distance to the nearest dam		1.000	0.999	1.000
		(-0.30)	(-0.51)	(0.07)
Perimeter-to-area ratio	0.099	0.038	0.047	0.029
	(-1.90)*	(-2.50)**	(-3.36)***	(-3.29)***
IUCN category II	5.633	4.232	4.912	5.421
	(1.89)*	(1.36)	(1.42)	(1.45)
IUCN category V	2.221	1.316	1.102	1.018
	(0.59)	(0.19)	(0.07)	(0.01)
IUCN category VI	2.768	2.013	2.041	2.236
	(1.39)	(0.83)	(0.82)	(0.88)
State dummies - Rôndonia as baseline				
Amapá	2.095	0.852	1.078	0.071
	(0.63)	(-0.11)	(0.06)	(-1.42)
Amazonas	0.098	0.084	0.054	0.004
	(-2.52)**	(-2.34)**	(-2.71)***	(-3.42)***
Maranhão	0.362	0.161	0.194	0.435
	(-0.58)	(-0.92)	(-0.80)	(-0.48)
Mato Grosso	0.046	0.019	0.016	0.015
	(-2.53)**	(-2.76)***	(-2.56)**	(-2.74)***
Pará	0.818	0.393	0.529	0.757
	(-0.22)	(-0.84)	(-0.57)	(-0.24)
Roraima	0.415	0.384	0.452	0.021
	(-0.61)	(-0.62)	(-0.52)	(-1.92)*
Pseudo R2	0.33	0.38	0.42	0.44
MacFadden's ajusted R2	0.20	0.22	0.22	0.25
AIC	216.50	211.25	203.42	195.86
Number of observations	292	295	287	287

* $p < 0.1$; ** $p < 0.05$; *** $p < 0$

Coefficients are displayed in odds ratio.

Z values are included in brackets.

Covariates which are not normally distributed (Average GDP, slopes, population density, total deforestation, distance to roads, river and forest edge) are included in logarithme.

We have added 1 to the variable that displays 0 in order to keep them when linearized.

Pailler, 2011; Mascia et al., 2014). However, the effet of the GDP may be partly taken into account in the state dummies as it is measured at the level of the municipality[6]. We rather think that the OCs of conservation driving the degazettement decisions are better approximated with land characteristics at the level of the CU.

When we look further into those characteristics in model (2), we first find a significant and positive effect of being located on higher slopes on the likelihood of degazettement. However, the influence of hydropower development on the likelihood of degazettement is not confirmed because of the lack of significance of the interaction between distance to river and slopes. We thus believe that CUs located on steeper terrain are less likely to face pressures (Joppa and Pfaff, 2009, 2011), which make them at least four times more likely to be removed due to their low potential additionality[7]. Then, we find a negative and significant effect of the distance to the nearest road that indicates that the remoteness of the CU to markets decreases by more than two times the likelihood of degazettement. The lack of significance of average rainfalls may be related to their unclear impact on agricultural activities as their profitability can be reduced when they turn to be excessive (Kere et al., 2017; Bax and Francesconi, 2018; Kirby et al., 2006). These results are consistent with land claims for agricultural extension, driven by the proximity of the CU to markets (Barber et al., 2014; Jusys, 2018), being an important proximate cause of degazettement (Symes et al., 2016; Laurance et al., 2014, 2009). Results in model (3) also confirmed this. Only the average population density in the 10km buffer zone of the CU has a strong and negative impact on its probability of being removed, which decreases by 51 to 55%. This result differs from that of Symes et al. (2016) who find the local population interacted with the size of the PA to be positively associated with PADDD due to land claims reasons. To go further, this external population density has been interacted with the distance of the CU to the nearest road. The negative effect of the population density on the likelihood of degazettement seems to be reinforced near roads. Here, we believe it may rather prevent the extension of agricultural and infrastructure projects or lower the pressures

[6]Without state dummies, results for the average GDP are highly significant. In addition, we have not been able to observe any impact of the average annual growth rate of the GDP from 2000 to 2005, which reinforce our idea that the effect of the development process is partly taken into account with the location of CUs within states. Results are available upon request.

[7]There are two other possible explanations for this result. First, without state dummies, the interaction between these covariates becomes significant, which make us think that the effect of hydropower development is linked to the location of CUs within the states of the Brazilian Amazon. Second, we use the average value of the slope over the CU, which may hide the existence of steep terrains suitable for such infrastructure development. However, results are the same when we use the standard deviation and the maximum value of the slopes over the CU.

through better enforcement (Naughton-Treves et al., 2005; Robinson et al., 2014; Pfaff et al., 2014). In model (3), unlike us, Tesfaw et al. (2018) find a significant and positive effect of deforestation inside the buffer zone of the CU in the state of Rondônia. This is not surprising as it is used as a proxy for the quality of enforcement[8].

Even though we have found a strong influence of development objectives in the degazettement decision process, environmental objectives seem to matter as well. First, the cumulated deforestation over 2001-2005 displays a non-linear effect on the likelihood of degazettement. Results indicate a negative effect of deforestation occurring in the area on the likelihood of degazettement, but only until a threshold (2.8 hectares of deforested area) where this effect reverse and become positive. This result is consistent with our expectation on the behavior of the EA. When pressures are low, lower forest clearings in CUs make the probability of enforcement high enough, degazettement is thus 32 to 39% less likely. When pressures increases, the probability of enforcement diminishes, which make the probability of being degazetted increasing by 2 to 3%. These results are close to those of Tesfaw et al. (2018) who use deforestation as an indicator of PAs effectiveness. Second, the perimeter-to-area ratio displays a strong and negative impact on the likelihood of degazettement. CUs with high perimeter-to-area ratio are 10 to 35 times less likely to lose their protection status. Indeed, they are less fragmented, which seems less costly to manage and enforce as a result of economies of scale (Bruner et al., 2004; Albers, 2010). The size of CUs, although it has not been included here due to its strong collinearity with the perimeter-to-area ratio, has a positive influence on the likelihood of degazettement. Larger PAs might be more costly to manage because it necessitates additional human and technical resources to enforce them (Veríssimo et al., 2011; Bruner et al., 2004; Robinson et al., 2011). One other possible explanation refers to the results of Symes et al. (2016) who find the size of PAs to be a strong predictor of PADDD due to their larger OC of conservation. We do not find any evidence that the expected environmental benefits in terms of biodiversity of maintaining PAs has an impact of the decision of degazettement. However, CUs are more likely to be degazetted when pressures are low because of low potential additionality. The lack of significance of the number of endemic species may be linked to the inclusion of state dummies as it is measured at a low level of aggregation[9].

[8]The inclusion of various measures to capture the difference between internal and external deforestation does not show any effect on the likelihood of degazettement (rate of change, subtraction and factor variables). The quality of enforcement seems to be already captured by our non-linear specification.

[9]Without state dummies and with clustered standard errors (table 9 in the Appendix), CUs that are endowed with a high number of endemic species show a lower likelihood of being degazetted.

We believe that, even if the results for the DAs and the EAs behavior are consistent across the Brazilian Amazon, their bargaining power differ according to the state in which CUs are located (Pfaff et al., 2015a,b; Nolte et al., 2013; Ferraro et al., 2013; Abman, 2018; Tesfaw et al., 2018). The characteristics of each state (e.g. the share of forest or agricultural activities, level of development, security of property rights...) may lead to different structure of conservation OCs and to the implementation of political incentives that are favorable either to environment or to development objectives[10]. CUs situated in Amazonas and Mato Grosso are at least 10 times less likely to be degazetted compared to those in Rôndonia. This state is situated in the arc of deforestation and has experienced numerous PADDD in 2010 and 2014 because of land claims for agricultural extension and for the construction of major hydroelectric dams (Tesfaw et al., 2018)[11]. Acre and Amazonas are states with lower development opportunities (Pfaff et al., 2014), which have a low OC of conservation compared to Rôndonia and where degazettements are the result of land claims for rural settlements. Mato Grosso is also situated in the arc of deforestation and is expected to have a high OC of conservation due to pressure coming for the agricultural sector, especially for the production of soy. However, it has few CUs and environmental objectives seem to have taken more importance from 2004 with the successful implementation of the PPCDAm and the soy moratorium in 2006 (Kastens et al., 2017; Veríssimo et al., 2011). We further investigate on this question by adding the distance to the forest edge in model (4). We observe that the distance to the forest frontier has a negative influence of the likelihood of degazettement, which may be link to lower pressure on the forest.

We think the DA is willing to take a degazettement decision as soon as the characteristics of the land make the profits from agricultural or infrastructure development positive. When pressures are high (e.g. low average external population density), this decision is likely to be fostered because of high management costs, even though they are well-enforced (figure 11) and discouraged otherwise.

[10]This can also be modified according to time periods. To address this, the regression has been estimated after 2008, when the second part of the PPCDAm (Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal - Action Plan for Prevention and Control of the Legal Amazon Deforestation) has been implemented. Results related to development objectives have more influence than before. To account for the effect of time, the age of the CU in 2005 has also been assessed and does not display any significance. Results are available upon request.

[11]Some states (Acre and Tocantins) don't show any degazettement events after 2005. For this reason, we have replaced them by clustered standard errors at the level of the state in table 9 in the Appendix. This allows the residuals to be correlated within states without loosing observations. We have 9 cluster, which is not enough to guarantee consistent estimates of standard errors (Cameron and Miller, 2015), however, we can't rely on non-parametric bootstrap as suggested by Esarey and Menger (2018) because we don't have enough variations within each cluster.

Figure 10: Interactions between average population density in the buffer zone and environment objectives

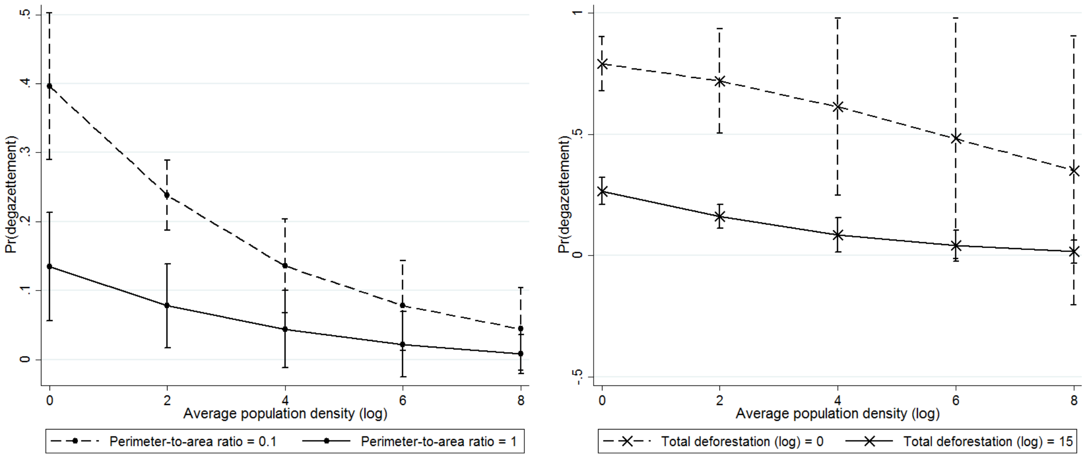
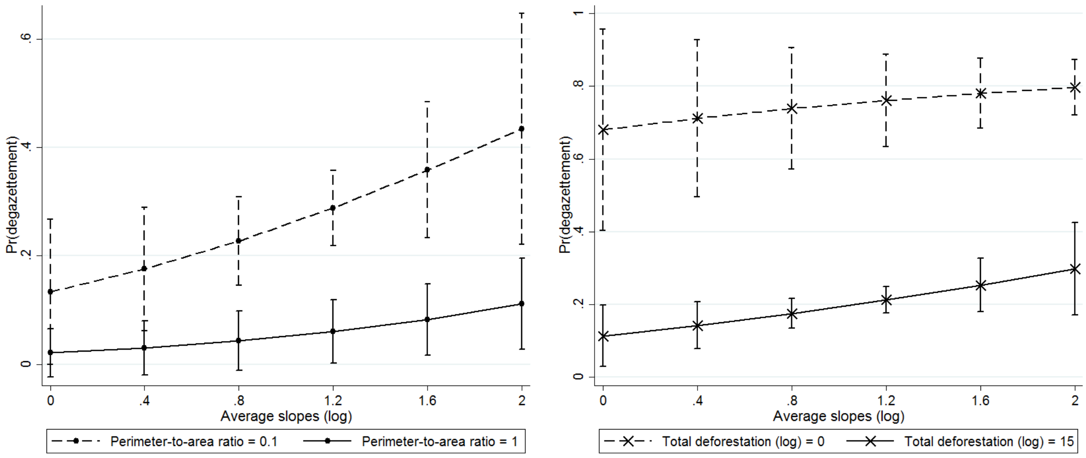


Figure 11: Interactions between slopes and environment objectives



Note: Margins are displayed with 95% confidence intervals

When pressures are low (e.g. steep slopes), degazettement may still happen when the quality of enforcement is high because of low expected additionality and high management costs (figure 10).

4.3.2 Robustness checks

We assess the characteristics of the land entering in the conservation OC as well as the weight given to environment and development objectives for subsets of CUs based on their location in states in the arc of deforestation, on their type and their level of governance[12].

In the basic specification, CUs that are near to the forest edge (i.e. in the arc of deforestation) are more likely to loose their protection status. In addition, in our sample, most CUs that have been degazetted are located in state in the arc of deforestation. For this reason, we assess the robustness of our results for CUs that are in the states of the deforested arc and more likely to face pressures (Pfaff et al., 2014, 2015a,b).

As indicated by the results for the arc of deforestation in table 2 below, the characteristics of the land entering in each agencies decision rule are not the same than those of the entire sample. First, environmental objectives have more weights in the decision process. CUs located near pressures, which are endowed with endemic species and which may represent management priorities to reach the biodiversity targets (Baldi et al., 2017), are 10 times less likely to lose their protection status. Besides, degazettements seem to be difficult to implement in CUs that does not allow resource use and access. PA with sustainable use of natural resources (IUCN category VI) are 5 times more likely to loose their protection status than strict nature reserve (IUCN category Ia) where both tourism and resource exploitation are strictly limited. Second, the conservation OCs entering in the DA decision rule is not composed of the same characteristics of the land. Indeed, in addition to the influence of roads, external population density and their interaction, we are able to observe an impact of the interaction between average slopes and rivers. This is expected to increase the profits from the construction of hydroelectric dams and contribute to a 16.5% rise of the likelihood of degazettement. This is in line with hydropower development being an important proximate cause of degazettement (Bernard et al., 2014; Pack et al., 2016; Mascia and Pailler, 2011; Mascia et al., 2014; WWF, 2017a; Tesfaw et al., 2018). We thus believe that being located in areas of highest pressures shape the composition of the conservation OCs for both the EA and the DA as well as the preferences toward environment and development objectives (Pfaff et al., 2009, 2014, 2015a,b; Jusys, 2018; Tesfaw et al., 2018).

[12] Results are presented without state dummies and with clustered standard errors because of the lack of observations, however, results for deforestation and development objectives are consistent with the inclusion of state dummies, which remains significants for Amazonas, Mato Grosso and also Maranhao compared to Rôndonia. This is available in table 9 in the Appendix.

In the basic specification, neither the type of CU nor its level of governance seems to enter in the choice of degazettement. In addition, PADDD events are evenly distributed across types and level of governance (Pack et al., 2016). However, CUs are not likely to face the same type of conservation-development trade-off depending on their characteristics (Ferraro et al., 2013; Nolte et al., 2013; Pfaff et al., 2014, 2015b, 2016; Kere et al., 2017; Tesfaw et al., 2018; Jusys, 2018). Moreover, PADDD decisions are not taken under the same type of decree depending on their level of governance (Bernard et al., 2014). For example, federal and mixed-use CUs are found to be more effective than state and strict CUs when they are located closer to threat. Even though they may be better enforced (Nolte et al., 2013; Ferraro et al., 2013; Jusys, 2018), their characteristics make them more likely to prevent local land use conflicts (Nolte et al., 2013; Pfaff et al., 2014; Kere et al., 2017). As a result, the characteristics of the land entering in each agencies decision rule as well as the weight given to environment and development objectives may differ according to PA type and level of governance (Ferraro et al., 2013; Nolte et al., 2013; Pfaff et al., 2015b, 2016; Kere et al., 2017; Tesfaw et al., 2018; Jusys, 2018).

We confirm that the characteristics of the land entering in each agency decision rule differ according to PA type and level of governance. Results in table 2 below indicate that CUs under mixed-use management are more likely to be degazetted due to their proximity to markets and low external population density. This confirms the importance of the extension of agricultural activities and is consistent with mixed-use CUs being located close to threat. In contrast, strict CUs are more likely to lose protection because of the characteristics of the land standing for land claims due to rural settlement (high internal population density and proximity to roads). The quality of enforcement has a larger influence in the EA decision rule for strict CUs, whereas that of mixed use CU is better approached with expected additionality and environmental benefits. Similarily to mixed-use CUs, those that are managed by federal government seems to be more influenced by the extension of agricultural activities through the proximity to rivers, roads, low internal average population density and their interaction. State-managed CUs are less influenced by the proximity to roads but are more likely to be degazetted when they have a high internal average population density. This is consistent with state and strict CUs being located farther from major threat and being degazetted mostly due to land claims conflicts (Pack et al., 2016). The EA decision rule is similar whatever the level of governance, however, it seems to have more weights for CUs managed at the federal level. It may indicate that the preferences toward environmental objectives are dependants on the state where CUs are located.

Table 2: Robustness checks

Logit (3)	Arc of deforestation	Strict	Mixed-use	National	Federal
The Development Agency					
Average slopes	3.524	1.860	10.517	0.589	118.985
	(3.84)***	(0.93)	(2.29)**	(-0.79)	(5.14)***
Distance to the nearest river	0.902	1.123	0.589	1.201	0.353
	(-0.54)	(0.27)	(-3.60)***	(0.50)	(-5.70)***
Average rainfalls	0.994	1.000	1.005	0.997	1.009
	(-1.44)	(0.02)	(0.89)	(-0.58)	(1.50)
Average rainfalls in the buffer zone	1.006	1.001	0.993	1.001	0.990
	(1.71)*	(0.41)	(-1.15)	(0.16)	(-1.51)
Average population density	1.921	3.416	0.546	3.163	0.201
	(1.46)	(2.04)**	(-0.67)	(1.84)*	(-5.02)***
Average population density in the buffer zone	0.791	0.929	0.621	0.536	0.641
	(-2.67)***	(-0.14)	(-2.14)**	(-1.41)	(-1.02)
Distance to the nearest road	0.317	0.472	0.268	0.427	0.193
	(-4.95)***	(-2.28)**	(-11.28)***	(-6.84)***	(-4.61)***
The Environment Agency					
Total deforestation	0.668	0.482	0.768	0.692	0.399
	(-3.50)***	(-2.78)***	(-1.45)	(-1.88)*	(-3.08)***
Squared total deforestation	1.025	1.044	1.023	1.026	1.051
	(4.12)***	(2.89)***	(3.20)***	(2.60)***	(4.84)***
Total deforestation in the buffer zone	1.033	1.015	0.939	0.972	0.995
	(1.64)	(0.19)	(-3.33)***	(-0.40)	(-0.09)
Perimeter-to-area ratio	0.071	0.000	0.097	0.037	0.000
	(-5.33)***	(-3.24)***	(-3.09)***	(-1.86)*	(-2.12)**
High endemism (>21)	0.002	1.196	0.168	0.053	0.016
	(-7.01)***	(0.15)	(-2.07)**	(-2.32)**	(-2.13)**
Low endemism (1-5)	0.028	3.152		0.587	0.199
	(-2.71)***	(0.79)		(-0.46)	(-1.25)
Medium endemism (6-20)	0.092	4.816	0.522	0.689	0.483
	(-2.73)***	(0.81)	(-1.20)	(-0.36)	(-0.62)
Distance to the nearest dam	1.003	0.993	0.998	0.991	0.998
	(0.94)	(-1.76)*	(-1.25)	(-1.62)	(-0.82)
IUCN category II	2.662			4.047	7.439
	(0.84)			(1.81)*	(6.96)***
IUCN category V	3.169			0.091	377.625
	(1.28)			(-1.16)	(6.01)***
IUCN category VI	5.105			7.795	5.601
	(2.44)**			(17.32)***	(2.98)***
Pseudo R2	0.41	0.42	0.42	0.46	0.57
MacFadden's ajusted R2	0.22	0.09	0.23	0.15	0.31
AIC	149.65	89.50	126.48	103.03	101.07
Number of observations	180	112	179	178	146

* $p < 0.1$; ** $p < 0.05$; *** $p < 0$

Coefficients are displayed in odds ratio.

Z values are included in brackets.

Covariates which are not normally distributed (Average GDP, slopes, population density, total deforestation, distance to roads, river and forest edge) are included in logarithme.

We have added 1 to the variable that displays 0 in order to keep them when linearized.

5 Discussion and conclusion

PAs are strong and widely used regulatory tools to limit resource use and access to land (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Their implementation may generate conflicts over land between conservation and development activities (Naughton-Treves et al., 2005; Deguignet et al., 2014; Watson et al., 2014). Evidences on the existence of such conflicts have been found: first, PAs tend to be located in low pressure areas (Joppa and Pfaff, 2009; Pfaff et al., 2015a; Baldi et al., 2017), which make them not as additional as expected in the fight against deforestation (Pfaff et al., 2009, 2014, 2015a,b, 2016; Andam et al., 2008; Joppa and Pfaff, 2011; Ferraro et al., 2013; Nolte et al., 2013; Sims, 2014; Anderson et al., 2016; Kere et al., 2017; Robalino et al., 2017; Jusys, 2018; Abman, 2018). Second, a worldwide phenomenon of PADDD has been observed since the last two decades, which seems to be driven by the development pressures (i.e. the OC of conservation) occurring in the landscape (Mascia and Pailler, 2011; Mascia et al., 2014; Pack et al., 2016; Bernard et al., 2014; Cook et al., 2017; de Marques and Peres, 2015; Symes et al., 2016).

In this article, we assess the possible drivers to the choice of withdrawing PAs in the Brazilian Amazon, where the conservation-development trade-off is a critical issue. Indeed, deforestation is rising and PAs are being removed due to development pressures (Veríssimo et al., 2011; Bernard et al., 2014; de Marques and Peres, 2015; Symes et al., 2016) even though strong efforts have been made to fight against deforestation and to extend the PA coverage. We have first proposed a simple economic model of degazettement choice where PADDD decisions are expected to be made through interactions between the decision rules of environmental and development agencies when the OC of conservation vary over the territory. We consider that the OC is a composite measure that encompasses several transmission channels. We suggest that the probability of being degazetted is large, either in places of low OCs, or in places of high OCs. When the OC of conservation is low, degazettements happen because of low environmental additionality, whereas it happens due to lack of enforcement and despite high potential additionality when it is low. Then, we have taken advantage of the PADDDtrack database (WWF, 2017b) to assess the OC of conservation with characteristics of the land and PAs and to investigate on the empirical determinants of PA withdrawal. We have used a logistic probability model in which the likelihood of degazettement is explained by a linear combination of characteristics of the land and PAs entering in each agencies' decision rules. The use of state dummies allows us to capture how the unobserved heterogeneity of the state influence PADDD decisions.

The likelihood of degazettement is strongly influenced by development objectives. We emphasize the positive role of the proximity to roads and the low external population density as it may increase the expected benefits from agricultural extension (Symes et al., 2016; Tesfaw et al., 2018; Barber et al., 2014; Jusys, 2018; Laurance et al., 2009, 2014; Finer and Jenkins, 2012; McClain and Naiman, 2008). In average, population pressure and infrastructure development does not seem to be strong predictors of degazettement (Symes et al., 2016) in our sample. The presence of human population does not necessarily rise the OC of conservation, either because it prevents the development of large-scale infrastructure or agricultural projects, or because it contributes to enhance protection (Blackman et al., 2015; Robinson et al., 2014; Pfaff et al., 2014). The construction of hydroelectric dams seems to have an influence on PADDD decision for CUs located in the states of the deforested arc, especially in Rondônia (Tesfaw et al., 2018). Environmental objectives also matter in the degazettement decision process. Assuming that CUs which have experienced forest clearings within their boundaries are badly enforced, we find a non-linear effect of deforestation on the likelihood of degazettement. CUs that have faced lower forest clearings have a lower probability of being badly enforced, which make them less likely to be degazetted. However, CUs that have undergone higher deforestation rates have a lower probability of being well enforced, which make them more likely to be degazetted. CUs are also more likely to lose their status of protection when they are situated in low pressure areas, which might represent the effect of low potential additionality. Lastly, we confirm the influence of the perimeter-to-area ratio as a predictor of degazettement due to the effect it has on the presence of economies of scale in PA management and enforcement (Veríssimo et al., 2011; Bruner et al., 2004; Sims, 2014; Albers, 2010).

Both the DA and the EA seem to behave as in our economic model. The probability of taking a degazettement decision for the DA increases with the OC of conservation due to favorable land characteristics rising the expected benefits of development activities. When economic pressures are high, degazettement decisions are either fostered or hindered by the quality of enforcement and management costs of PAs. When economic pressures are low, degazettement decision may still happen because of low expected additionality, especially when CUs are costly to manage. The inclusion of state dummies makes us emphasize that the weight of environment and development objectives may be modified by the political incentives implemented either toward development or environment objectives (Bernard et al., 2014; Pack et al., 2016; Mascia and Pailler, 2011; Mascia et al., 2014). In addition, the characteristics of the land and PAs entering in the conservation OCs of each agencies decision rule differ according to PA location, type and level of governance. Therefore, the weight given to environment and development objectives may be modified, especially for PAs managed at the decentralized level and nearest to pressure (Ferraro et al., 2013; Nolte et al., 2013; Pfaff et al., 2009, 2014, 2015a,b, 2016; Kere et al., 2017; Tesfaw et al., 2018; Jusys, 2018). Our findings are consistent with the way PADDD decision are taken in Brazil. Even though some of them have come from appropriate adjustments of PA network to remove protection when it was not effective, this has not been the rule and has not been used a lot to consolidate protection in needed areas (Bernard et al., 2014; Mascia and Pailler, 2011; Mascia et al., 2014). Most of the time, decision makers are sensible to local interests and lobbying while the ministry of environment lack the capacity to mobilize political interest (Bernard et al., 2014; Ferreira et al., 2014; Pack et al., 2016; Mascia and Pailler, 2011; Mascia et al., 2014).

The environmental effects of PADDD are not well-known (Forrest et al., 2015; Golden Kroner et al., 2016; Tesfaw et al., 2018; Pack et al., 2016) but this phenomenon is not likely to decrease, especially due to the ambitions to foster the construction of hydroelectric dams and to reinforce the mining industry in the territory (WWF, 2017c; Pack et al., 2016; Araújo et al., 2012; Ferreira et al., 2014; de Marques and Peres, 2015). Even though some PAs may lose protection due to low expected additionality in the absence of major threat, those located close to economic pressures are those suffering the most from PADDD (Bernard et al., 2014; Ferreira et al., 2014; Pack et al., 2016; Mascia and Pailler, 2011; Mascia et al., 2014). PADDD in low pressure areas can be useful to consolidate protection in high threat areas where financial and technical ressources are needed for better management (Fuller et al., 2010; Cook et al., 2017; Bernard et al., 2014; Mascia and Pailler, 2011; Mascia et al., 2014). However, they may still provide environmental benefits in terms of biodiversity maintenance and as safeguards in front of future threats (Ferreira et al., 2014; Mascia et al., 2014). Deciding PADDD would therefore require a defined and structured decision process based on public consultation and on technical studies regarding their ecological and social impacts (Ferreira et al., 2014; Symes et al., 2016).

In the Brazil Amazon, even though some PADDD are proposed and other enacted, neither the process of degazettement nor the sequence of events are observed.That is why we have focused our model on detailing the preferences of each actor and their possibles interactions. Further work should focus on enhancing the model to better understand the dynamic of decisions and the bargaining between actors. One other extension should be to investigate on the spatial interactions that could influence decision makers to withdraw PAs. Spatial interactions may first occur during the creation of PAs because they generate global benefits while managing them implies local costs (Sauquet et al., 2014). In this work, we have accounted for the effect of spatial heterogeneity on the conservation OCs by including state dummies and by breaking down our sample according to characteristics of the land and of PAs. Indeed, taking into account spatial interactions would first necessitate to understand the mechanisms through which decision makers may be influenced by their neighbors when they take a PADDD decision. Downsizement and degazettement are not the same type of events and might come from various composition of conservation OCs and preferences toward environment and development objectives. Even though they stand for a loss of protection for a unit of PA, they should be compared with caution. This will be possible once more data is made available. At last, further work should consist in assessing the impacts of PA withdrawal in the Brazilian Amazon over the period under consideration. In order to isolate the differences in impact when the OC of conservation vary, PAs with the same level of economics pressure as well as the same composition of conservation OCs should be used. This might provide valuable insights so that the impermanance of PAs could be taken into account when evaluating the impact of conservation instruments (Tesfaw et al., 2018). This may help to inform decision makers on how to deal spatially with the conservation-development trade-off when designing more robust and dynamic conservation policies (Fuller et al., 2010; Ferreira et al., 2014; Mascia et al., 2014; Symes et al., 2016).

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6 Appendix

Functional forms and parameters used for the simulations

$$
\begin{aligned}
C_i(o_i) &= h_i + \frac{1}{a}o_i^a \\
p_i(o_i) &= 1 - (\frac{o_i}{1+o_i})^b \\
e_i(o_i) &= so_i^d \\
U_{DA}(D_i) &= wo_iD_i \\
B_i(o_i) &= h_i + \frac{1}{a}o_i^a - (1 - (\frac{o_i}{1+o_i})^b)so_i^d \\
U_{EA}(D_i) &= B_i(o_i)D_i
\end{aligned}
\tag{11}
$$

Table 3: Parameters values

Variable	Value
o_i	$\in [0, 10]$
h_i	10
a	3
b	0.8
d	0.8
s	50
w	10

Specific cases

Specific cases in which no degazettement is implemented in the LB channel (figure 12) can be driven by negligible fixed costs in the EA's net benefits from PA degazettement. Yet, PA degazettement will always happen in the HC channels because of increasing variables costs and decreasing environmental benefits with OCs. In addition, sufficiently high fixed costs will result in PA degazettement for all value of OCs (figure 13).

Figure 12: Negative and positive net losses from PA management

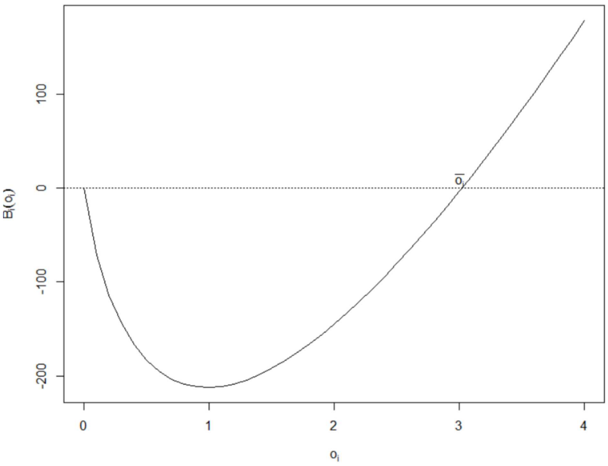
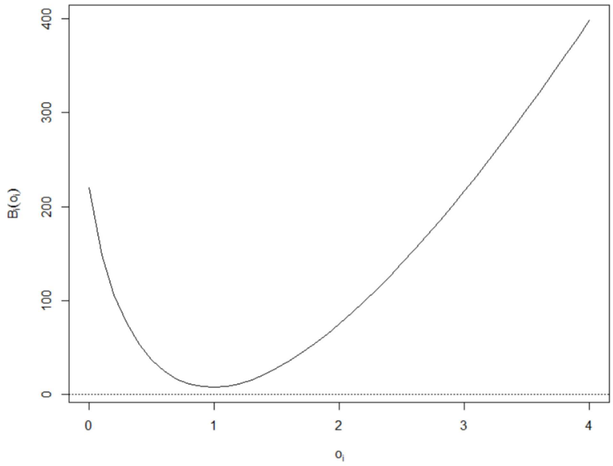


Figure 13: Positive net losses from PA management



Cooperative game

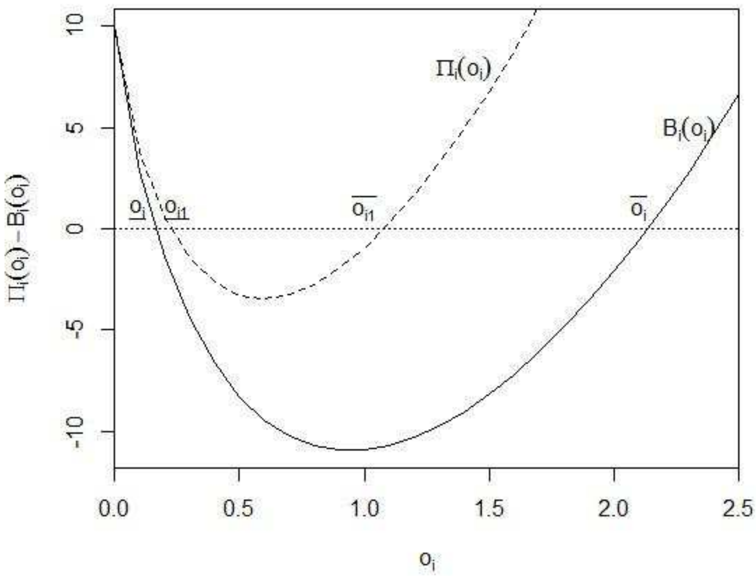
Here, we assume that both the EA and the DA are cooperating in order to know the value of development pressures for which one area will be degazetted. They take their decision by maximizing their joint payoff $\pi_i(o_i)$.

$$\pi_i(o_i) = B_i(o_i) + w(o_i) \tag{12}$$

They take their cooperative decision by following a decision rule CG with the objective of maximizing their joint payoff from PA degazettement (equation 14). As in the precedent case, PAs are degazetted as soon as the overall management cost from their maintenance is higher than the difference between their expected environmental benefits and the potential expected profits from their degazettement.

$$\begin{aligned} CG(D_i) &= \pi_i D_i \qquad (13)\\ D_i &= 1 \ \forall \ wo_i > b_i(o_i) - C_i(o_i) \\ D_i &= 0 \ \forall \ wo_i \leq b_i(o_i) - C_i(o_i) \end{aligned}$$

Figure 14: Joint payoff from PA degazettement



The joint payoff from PA degazettement is greater in the case of cooperation. Here, compared to the case where the EA where considered as the only decision makers, the inclusion of the DA's payoff makes π_i higher for each value of OCs (figure 14). However, the dividend of cooperation will not be the same for each agency. Indeed, for each value of OCs, the decision rule that predominate is that of the agency who values the area the most either for conservation or for development objectives.

For PAs whose OCs are lower than $\underline{o}_i$ or higher than $\bar{o}_i$, both agency agree on degazettement as their individual benefits are positive. However, the values of $\underline{o}_{i1}$ and $\bar{o}_{i1}$ for which they cooperate are respectively higher and lower (figure 14). Their cooperation result in more PA degazettement both in the LB and in the HC channels. The effect is greater in the HC channel because the DA expected payoff is increasing in o_i and the EA expected environmental benefits are decreasing fastly compared to her overall management costs.

In order for the cooperation to be stable, compensation through transfer payments can be done i) by the DA to the EA for the loss of PAs that were supposed to be maintained in the absence of cooperation and ii) by the EA to compensate the DA for the foregone expected development profits of non degazetted PAs. One solution to share the benefits of cooperation in a fair and Pareto-improving way is to use the Nash bargaining procedure. Each agency can thus recover her non cooperative outcome and half of the dividend of their cooperative outcome.

Description of covariates

Table 4: Source and description of variables

Variable name	Date	Source	Treatment
The Development Agency			
GDP	2000 to 2005	Vector format from the IBGE at the level of the municipality in current prices (1000 real) (IBGE, 2017)	Average from 2000 to 2005. Rate of change from 2000 to 2005.
Slopes	-	Gridded elevation data from the Shuttle Radar Topography Mission (SRTM) (Jarvis et al., 2008). 90m resolution resampled in 250 by 250 meters.	Computed in degree from the horizontal over each observation unit with ArcGIS.
Distance to the nearest river	-	Lake, pond and rivers, permanent and navigable. Vector format from the IBGE (IBGE, 2017)	Distance of the centroid of each CU to the nearest river in kilometer with ArcGIS.
Rainfalls	2000 to 2005	Gridded annual data from the version 2.0 of Climate Hazard Group InfraRed Precipitation with Station Data (CHIRPS) (Funk et al., 2015). 0,05 degrees of resolution.	Average from 2000 to 2005 in millimeter per year.
Population density	2000 and 2005	Gridded data from The Gridded Population of the World (GPW) version 4 from the 2006 Global Rural-Urban Mapping Project (GRUMP) of the Center for International Earth Science Information Network (CIESIN, 2015) .	Average between 2000 and 2005.
Distance to the nearest road	2006	Vector format from the Brazilian Departamento Nacional de Infraestrutura de Transportes (DNIT, 2017)	Distance of the centroid of each CU to the nearest roads in kilometer with ArcGIS.
The Environmental Agency			
Quality of enforcement			
Total deforestation	2001 to 2005	Vector format from the PRODES System of the Instituto Nacional de Pesquisa Espacial (INPE) (INPE, 2017)	Total from 2001 to 2005 in hectares.

Expected environmental benefits			
Number of endemic species	-	Vector format from the WWF WildFinder database of species distributions (WWF, 2006; Olson et al., 2001). High endemism: from 21 to 47 endemic species; medium endemism: from 6 to 20 endemic species; low endemism: from 1 to 5 endemic species; no endemism (0 endemic species) is the baseline.	-
Distance to the nearest dam	from 1975 to 2005	More than 0,1km^3. Point format from the Global Reservoir and Dam (GRanD) database of the Department of Geography of Mc Gill University in Montreal (Lehner et al., 2011).	Distance of the centroid of each CU to the nearest dam in kilometer with ArcGIS.
Management costs			
PA size	-	WDPA (IUCN and UNEP-WCMC, 2017) PADDDtracker (WWF, 2017b)	-
Perimeter-to-area ratio	-	WDPA (IUCN and UNEP-WCMC, 2017) PADDDtracker (WWF, 2017b)	Ratio of perimeter to area
IUCN category	-	WDPA (IUCN and UNEP-WCMC, 2017) PADDDtracker (WWF, 2017b) II: National Parks; V: Protected Landscape; IV: Habitat/Species Management Area; Ia (Strict Nature Reserve) is the baseline.	-

Descriptive statistics

Table 5: Dependants variables

	(1)				(2)			
	Mean	Sd	Min	Max	Mean	Sd	Min	Max
Average GDP	867005	2987223	3281	2.01e+07	1580397	3953781	16602.65	2.01e+07
Average annual growth rate of GDP	.1764954	.0795423	.0415059	.7141291	.182938	.0458108	.0887673	.2776018
Distance to the nearest road	84.94507	77.11468	.1455309	400.3318	56.34097	55.71756	2.445773	274.2852
Average slopes	1.683822	1.390251	.1502362	8.187457	2.053847	1.107261	.4287834	6.929451
Average raifalls	2086.795	454.0254	880.1189	3297.514	2046.041	315.8289	1266.997	2975.134
Distance to the nearest river	46.40741	54.80917	0	306.1169	43.26907	46.93101	0	270.2112
Average population density	164.5872	830.9477	.0003693	8815.419	62.5102	424.6055	.0014448	3032.622
Total deforestation	190.1716	1430.686	0	23571.35	1145.235	2090.466	0	8318.601
Distance to the nearest dam	343.5179	205.6618	36.33719	1065.188	282.3625	181.9039	6.775725	643.929
PA size	3668.874	6721.194	.0154457	48266.96	7115.22	8867.872	.5375	38870
Perimeter-to-area ratio	1.778855	6.564327	.0342063	74.20567	.1772181	.2577897	.0001072	1.339837
Observations	286				51			

Note: Sd, Min and Max respectively stand for Standard deviation, Minimum and Maximum.

	(1)		(2)	
	Obs	Freq	Obs	Freq
high endemism (>21)	59	20.84806	2	3.921569
low endemism (1-5)	107	37.80919	19	37.2549
medium endemism (6-20)	74	26.14841	20	39.21569
no endemism (0)	43	15.19435	10	19.60784
Total	283	100	51	100
Observations	283		51	

Note: Obs and Freq respectively stand for Number of observations and Frequency.

Table 6: Number of terrestrial endemic species

	(1)		(2)	
	Obs	Freq	Obs	Freq
II	58	20.27972	14	27.45098
III	5	1.748252		
IV	24	8.391608		
Ia	33	11.53846	4	7.843137
V	41	14.33566	4	7.843137
VI	125	43.70629	29	56.86275
Total	286	100	51	100
Observations	286		51	

Note: Obs and Freq respectively stand for Number of observations and Frequency.

Table 7: IUCN categories

Table 8: Pearson's correlations

	(1)	
	Parameter	P-value
Average GDP	.1378954	.081476
Average annual growth rate of GDP	.5752871	.0312399
Distance to the nearest road	.011788	-.1370489
Average slopes	.072625	.0979184
Average rainfalls	.5391911	-.033564
Distance to the nearest river	.7008992	-.0209994
Average population density	.3922057	-.046827
Total deforestation	.0000608	.216621
Distance to the nearest dam	.0475284	-.1080278
PA size	.0015004	.1722776
Perimeter-to-area ratio	.0827641	-.0946437
Number of endemic species	.0078924	.1451385
IUCN category	.8657652	.0092423
Observations	337	

Estimations

Table 9: Alternative estimations

Variables	Basic specification	Robustness checks: Arc	Strict	Mixed-use	National	Federal
The Development Agency						
Average slopes	5.248	3.111	1.679	13.645	0.366	939.007
	(2.72)***	(1.47)	(0.47)	(2.33)**	(-0.76)	(2.86)***
Distance to the nearest river	0.695	0.941	0.839	0.667	1.551	0.179
	(-2.31)**	(-0.17)	(-0.39)	(-1.12)	(0.43)	(-2.46)**
Average rainfall	1.001	0.999	0.991	1.005	1.006	1.000
	(0.46)	(-0.14)	(-1.36)	(0.93)	(1.02)	(-0.04)
Average rainfall in the buffer zone	0.998	1.001	1.007	0.995	0.993	1.007
	(-0.52)	(0.15)	(1.16)	(-0.82)	(-0.97)	(0.70)
Average population density	1.556	1.933	3.794	1.918	872.561	0.030
	(0.97)	(1.36)	(1.54)	(0.63)	(2.20)**	(-1.36)
Average population density in the buffer zone	0.546	0.711	1.560	0.478	0.208	0.238
	(-2.58)***	(-1.12)	(1.06)	(-1.31)	(-1.07)	(-1.00)
Distance to the nearest road	0.432	0.332	0.298	0.248	0.257	0.167
	(-5.76)***	(-2.99)***	(-2.16)**	(-2.81)***	(-1.67)*	(-2.92)***
The Environment Agency						
Total deforestation	0.658	0.630	0.354	0.712	1.167	0.505
	(-6.97)***	(-2.15)**	(-2.42)**	(-1.27)	(0.15)	(-1.14)
Squared total deforestation	1.028	1.027	1.060	1.020	0.998	1.049
	(7.84)***	(2.54)**	(2.38)**	(1.65)*	(-0.03)	(1.82)*
Total deforestation in the buffer zone		1.042	1.045	0.967	0.940	0.980
		(1.02)	(0.59)	(-0.76)	(-0.64)	(-0.25)
Distance to the forest edge	1.071					
	(0.39)					
High endemism (>21)	0.097	135,280.464	17.228	0.022	4.435e+15	0.000
	(-2.53)**	(5.71)***	(1.01)	(-1.57)	(9.52)***	(-3.40)***
Low endemism (1-5)	0.337	0.031	7.838		4.279e+20	0.000
	(-1.06)	(-2.44)**	(1.02)		(5.97)***	(-3.02)***
Medium endemism (6-20)	0.781	0.086	13.098	0.028	0.002	0.010
	(-0.37)	(-2.60)***	(1.33)	(-1.41)	(-1.99)**	(-2.23)**
Distance to the nearest dam	0.998	1.003	0.994	1.004	1.000	0.996
	(-1.08)	(1.44)	(-1.29)	(1.15)	(0.02)	(-1.22)
Perimeter-to-area ratio	0.065	0.090	0.000	0.028	0.000	0.000
	(-3.30)***	(-2.45)**	(-2.67)***	(-2.60)***	(-2.31)**	(-2.10)**
IUCN category II	2.849	3.811			10.834	80.845
	(1.32)	(0.94)			(1.27)	(2.64)***
IUCN category V	0.462	4.124			0.000	50,964.231
	(-0.57)	(0.87)			(-3.52)***	(3.11)***
IUCN category VI	2.087	5.224			77.555	23.858
	(1.12)	(1.46)			(2.58)***	(2.42)**
State dummies						
Amapá			38,534.296	0.092	0.000	1.234
			(2.54)**	(-0.95)	(-5.09)***	(0.08)
Amazonas			4.713		0.000	0.001
			(0.93)		(-5.53)***	(-2.97)***
Maranhão			0.162			15,967.933
			(-0.79)			(2.86)***
Mato Grosso		0.000	0.000		0.000	
		(-16.00)***	(-1.40)		(-4.39)***	
Pará		0.756	4.629	0.096		1.867
		(-0.21)	(0.96)	(-1.15)		(0.31)
Roraima				0.009		0.053
				(-1.33)		(-1.25)
Pseudo R2	0.35	0.45	0.53	0.49	0.78	0.65
MacFadden's ajusted R2	0.22	0.23	0.08	0.22	0.38	0.29
AIC	215.86	146.81	85.10	102.91	67.68	93.87
Number of observations	325	180	96	112	132	120

* $p < 0.1$; ** $p < 0.05$; *** $p < 0$

Coefficients are displayed in odds ratio.

Z values are included in brackets.

Covariates which are not normally distributed (Average GDP, slopes, population density, total deforestation, distance to roads, river and forest edge) are included in logarithme.

We have added 1 to the variable that displays 0 in order to keep them when linearized.